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1. WÄRTSILÄ 50DF LNG FSRU POWER PLANT EXHAUST GAS EMISSIONS

The report describes the values that are achievable with the 50DF engines for the Cabrillo port LNG terminal project. Guarantees of these values are included in a technical specification and offer. In the chapter 1.2 the emission levels out of the engine are described and in chapter 1.3 the emissions out of a power plant fitted with emission reduction methods and analysed. It should be notable that the one emission level given is this document can be further improved but might have negative impact on other emissions levels. Therefore; if some special emission requirements occur they can be treated case by case.

All measurements and emission limits are done according to chapter 1.4.

1.1 FUEL DATA

The exhaust gas emissions are given according to a fuel gas specification below:

1.1.1 Gas specification (at 0 °C , 100 kPa)

	vol %
CH4	99,66804
C2H6	0,111987
C3H8	0
n-C4H10	0
i-C4H10	0,009999
n-C5H12	0
i-C5H12	0
n-C6H14	0
n-C7H16	0
N2	0,189977203
O2	0,0099988
CO2	0,0099988
H2S	0
H2	0
H2O	0
CO	0
Ar	0
He	0

1.2 50DF ENGINE EMISSONS

Table 1. Emission levels from 50DF engine without emission reduction (1

FUEL : Natural gas (2					
Unit	NO_x	CO	VOC	SO_x	$PM_{10,dry}$
g/kWh	1.5	1.06	0.431	0.0759	0.0662
Vol-ppm, dry at 15% O_2	135	128	87	4	
mg/m3					10

FUEL : Marine diesel oil					
g/kWh	14,7	1.03	0.651	0.0835	0.154
Vol-ppm, dry at 15% O_2	970	111	123	4	
mg/m3					21

(1 Values given at 90% load

(2 only valid with the fuel gas defined

1.3 50DF POWER PLANT (WITH SCR AND OXIDATION CATALYST) EMISSIONS

This chapter describes the emission limits that are achievable with appropriate emission reduction methods on a 50DF power plant. The emission reduction can be optimised for gas fired operation or Marine diesel operation. This project focus on utilising natural gas as fuel and therefore the values are optimised according to gaseous fuel operation.

The emission levels on diesel can also be reduced; however these are not of highest priority and therefore not optimised in this evaluation.

Table 2. Emission levels from 50DF power plant with SCR and oxidation catalysts emission reduction (1

FUEL : Natural gas (2					
Unit	NO_x	CO	VOC	SO_x	$PM_{10, dry}$
g/kWh	0.10	0.17	0.20	0.0759	0.0662
Vol-ppm, dry at 15% O_2	9	20	40	4	
mg/m3					10
FUEL : Marine diesel oil					
g/kWh	14,7	1.03	0.651	0.0835	0.154
Vol-ppm, dry at 15% O_2	970	111	123	4	
mg/m3					21

(1 Values given at 90% load

(2 only valid with the fuel gas defined

This chapter describes emission levels that are achievable with a DF power plant fitted with selective catalytic reduction. The values are only valid for Wärtsilä supplied equipment. The technical particulars are only described in the technical specification.

1.4 MEASURING METHODS

Emission values are based on and valid only on following or principally similar measurement methods and limits:

1.4.1 Nitrogen oxides (NOx)

USA EPA Method 7E: Determination of nitrogen oxides from stationary sources

(instrumental analyzer method).

1.4.2 Sulphur oxides (SOx)

After engine (no deSOx equipment installed)

ISO/CD 8178-1 : Sulphur oxides are calculated from sulphur content in the fuel.

1.4.3 Carbon monoxide (CO)

USA EPA Method 10 : Determination of carbon monoxide emissions from stationary sources.

1.4.4 Total Hydrocarbons (THC)

USA EPA Method 25A: Determination of total gasous organic concentration using a flame ionisation analyzer (FID).

1.4.5 VOC (NM/NEHC) after engine (no catalyst installed)

USA EPA Method 25A: Determination of total gasous organic concentration using a flame ionisation analyser. None Methane None Ethane Hydrocarbons are defined as total hydrocarbons (THC) excluding metane and ethane. The methane and ethane concentrations in the exhaust gas are calculated based on the fuel analysis. The ratio of methane and ethane to THC in the fuel gas remain constant in the exhaust gas.

1.4.6 VOC (NM/NEHC) after an oxidation catalyst

USA EPA Method 18: Measurement of gaseous organic compound emissions by gas chromatography. VOC is defined as Non Methane Non Ethane Hydrocarbons. Measured components are C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, C_2H_4, C_3H_6, C_4H_8, C_5H_{10} and C_6H_{12}. Formaldehyde concentration is negligible after a catalyst. If required this can be verified with method CTM-037.

1.4.7 Particulates

PM (Particulate matter as dry dust).

ISO 9096: Determination of particulate emissions from stationary sources (in stack method)

USA EPA Method 17: Determination of particulate emissions from stationary sources (in-stack method).

1.4.8 Filterable PM10

USA EPA Method 17: Determination of particulate emissions from stationary sources (in-stack method)

USA EPA Method 201A (front half): Determination of filterable PM10 emissions

(in-stack filter method with sizing device)

1.4.9 PM (Particulate matter as dry dust) when flue gas temperature is < 160C eg after heat recovery boiler

ISO 9096: Determination of particulate emissions from stationary sources.

USA EPA Method 5B: Determination of particulate emissions from stationary sources.

1.4.10 Measurement uncertainties

Measurement uncertainties to be evaluated by the party that carries out the measurement.

The assessment of the guarantee fulfilment to be performed according to Section 6.2 of the VDI 2048 guidelines.

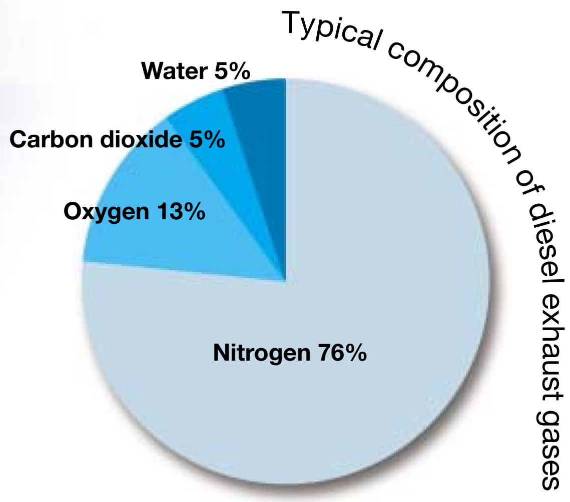
The EnviroEngine Concept

The EnviroEngine Concept

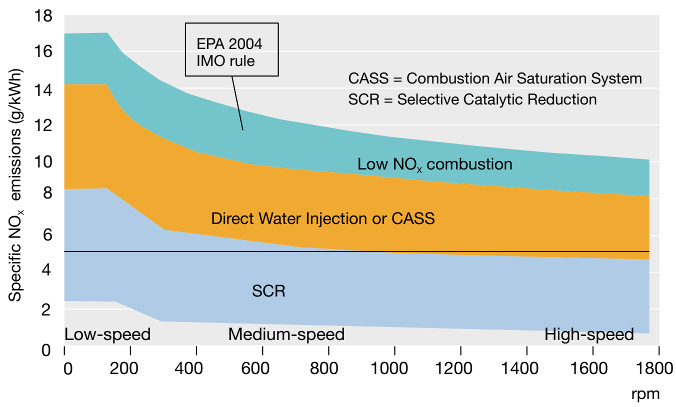
To meet the increasing pressure to make ships more environmentally friendly Wärtsilä is committed to keeping well ahead of international environment regulations and legislation.

Wärtsilä's aim is to provide shipowners with the most environmentally sound prime movers without compromising overall operational economy. All experience and research effort have been gathered in the EnviroEngine concept. EnviroEngines combine several innovative Wärtsilä technologies such as Common Rail Fuel Injection, Direct Water Injection and Selective Catalytic Reduction.

The EnviroEngine stands for continuous and systematic refinement of the means and solutions for running marine engines at maximum efficiency while eliminating visible smoke, and minimizing the exhaust emissions of carbon dioxide, sulphur and nitrogen oxides formed in the combustion process.



Nitrogen 76%, oxygen 13%, carbon dioxide 5% and water 5% = about 99.5%. Other emissions: nitrogen oxides, carbon monoxide, hydrocarbons, particulates.



NO_X emissions compliance of Wärtsilä engines.

The Queen Mary 2, with four Wärtsilä 16V46 common rail engines, is not only the world's largest cruise ship but also the first passenger liner to have been built for many years.

The common rail system – The Smokeless Engine

Most harbours in the world are located close to densely populated areas, and the demand for no visible smoke under any circumstances has become increasingly important in recent years. State-of-the-art common rail injection technology now makes it possible to provide smokeless engines. Wärtsilä has the widest range of products available with common rail technology for heavy fuel operation.

Technology for 4-stroke common rail engines

The design of common rail technology on 4-stroke engines consists of fuel pumps, which feed pressurized fuel oil to accumulators connected to electronically controlled fuel injectors in two cylinders. The accumulators are connected with piping, which is called the common rail. The fuel pumps are driven by the camshaft of the engine. Since the timing of fuel pumping is not connected to the timing of injection, one revolution of the camshaft can include two fuel pumping cycles. This means that fewer pumps can be used than in conventional systems since one pump is enough to feed fuel into two cylinders. All functions are controlled by an integral control system on the engine.

The common rail system design is optimized for new engines but it can also be retrofitted to existing engines.

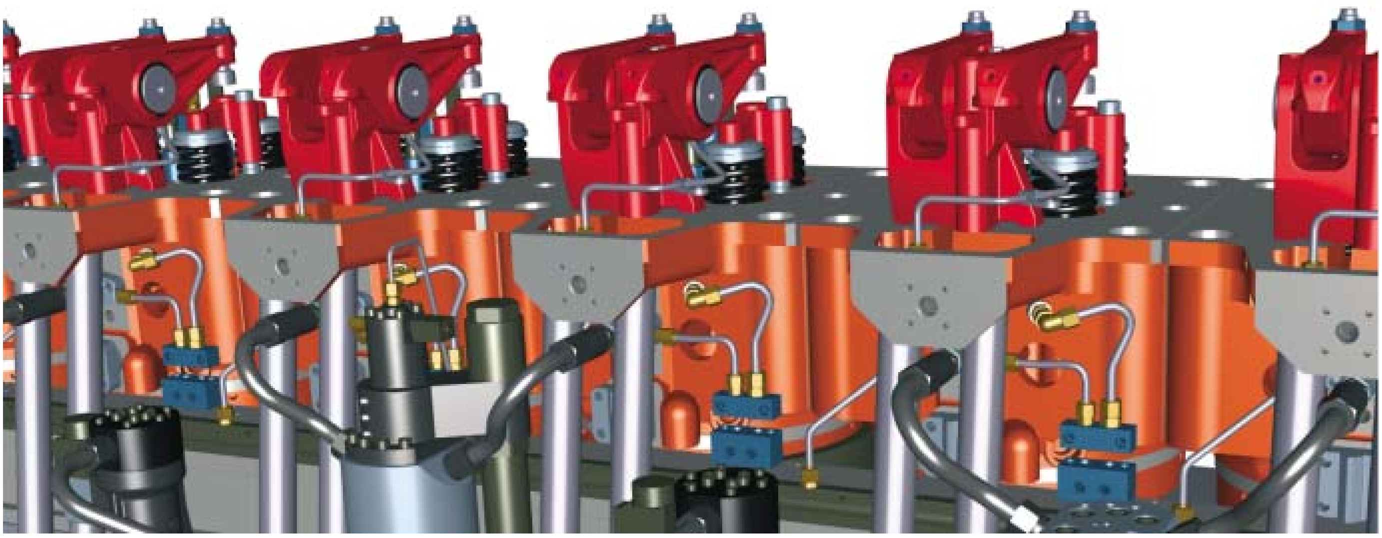
Common rail is available for the WÄRTSILÄ® 32, Wärtsilä 38 and Wärtsilä 46 engines and is being continuously developed for additional Wärtsilä engines.

Technology for 2-stroke Sulzer RT-flex engines

The RT-flex engine is basically a standard SULZER® RTA low-speed engine from which the camshaft and its gear drive, the complete fuel injection pump units and the related mechanical control gear have been removed. These parts are replaced by four principal elements: the rail unit along the side of the cylinders, the supply unit on the side of the engine, the filter unit for servo oil, and the integrated electronic control system. The common rail is a pipe running the length of the engine just below the cylinder cover level and is fed with heated fuel oil at a pressure up to 1000 bar. Fuel is delivered from the common rail through a separate injection control unit for each engine cylinder to standard fuel injection valves. The control units regulate the timing of fuel injection, control the volume of fuel injected and set the shape of the injection pattern.

Common rail is available in the Sulzer RT-flex50, RT-flex58T, RT-flex60C, RT-flex84T, RT-flex96C and is being continuously developed for additional Sulzer engines.

Wladyslaw Orkan, multi-purpose container carrier with a Sulzer RT-flex60C engine.



Design of common rail for 4-stroke engines.

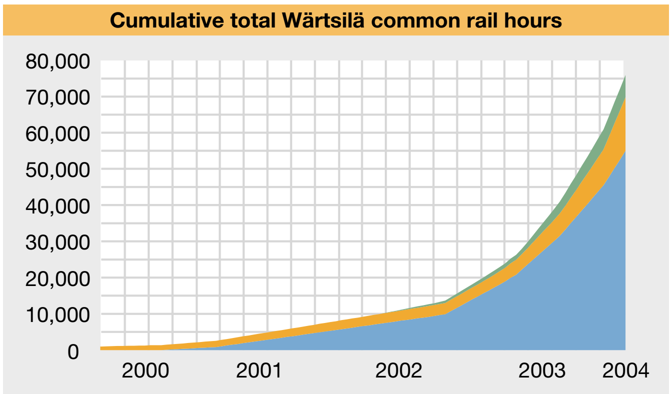
Benefits of common rail

Smokeless operation is demonstrated on all speeds and loads. Superior combustion is achieved by keeping the fuel injection pressure at the optimum level right across the engine speed range.

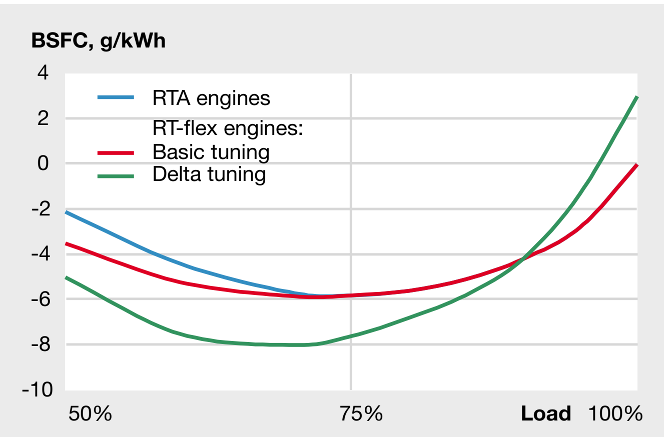
Lower, stable running speeds are available with common rail. This is especially important with 2-stroke engines, which are usually connected to fixed pitch propellers. Speeds down to about 10 rpm for the engines are possible.

Reduced fuel consumption at part load is seen when compared with the existing engines. High injection pressures enable perfect atomization and thus also high efficiency.

Operational experience



Experience of 4-stroke common rail engines.



New Delta tuning gives a lower BSFC curve for the RT-flex engine, compared with the original BSFC curves of the Sulzer RTA and RT-flex engines. All curves shown are for engines complying with the IMO NO_X regulation.

Benefits of common rail

- Smokeless operation on all speeds and loads
- Superior combustion achieved by keeping the fuel injection pressure at the optimum level
- Lower and stable running speeds
- Reduced fuel consumption at part load

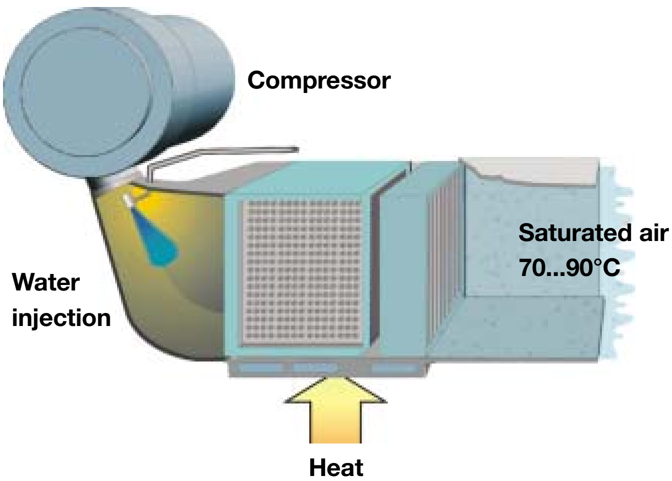
Humidification technologies

Water can be used effectively to limit NO_X formation by reducing temperature peaks during the combustion process.

CASS

The newest NO_X reduction technology developed by Wärtsilä is called CASS – Combustion Air Saturation System. The principle of CASS technology is to introduce pressurized water into the combustion process to reduce NO_X formation. The pressurized water is added to the intake air after the turbocharger compressor. Due to the high temperature of the compressed air, the water evaporates immediately and enters the cylinders as steam, thus lowering the combustion temperatures and the formation of NO_X.

CASS technology has so far been developed for the Wärtsilä 20, 32 and 46 engine types, and the first pilot installation was commissioned in 2003. The anticipated NO_X reduction is up to 50%, and the water consumption is expected to be about two times the fuel oil consumption.



Working principle of the Cass system.

Direct Water Injection

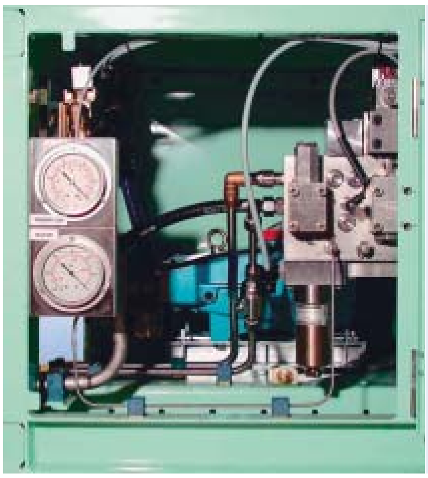
The Direct Water Injection technique reduces NO_X emissions typically by 50-60 % without adversely affecting power output. Built-in safety features enable immediate water shut-off in the event of excessive water flow or water leakage. The water system is completely separate from the fuel system: if water shut-off should prove necessary, engine operation is not affected. The key is the DWI valve through which the water and fuel are injected, typically in a water-to-fuel ratio of 0.4-0.7.

M/S Mistral delivered to Godby Shipping in January 1999 – one of the first of seven forest product carriers equipped with Direct Water Injection.

The best environmental performance is achieved by combining the use of DWI with low-sulphur fuel. DWI technology is not recommended with high-sulphur fuels (over 3%).

The combined nozzle for direct water injection.

DWI units for pressurizing water.



The benefits of Direct Water Injection

- NO_X emissions are reduced by 50 - 60 %.
- NO_X when running on marine diesel oil (MDO) typically 4-6 g/kWh; in HFO operation typically 5-7 g/kWh.
- The engine can also be operated without water injection if required.
- The engine can be transferred to "non-water" operational mode at any load.
- In alarm situations transfer to "non-water" mode is automatic and instant.
- Space requirements for the equipment are minimal and therefore the system can be installed in all installations.
- Investment and operational costs are low.
- Ratio of Injected water to injected fuel typically 0.4 - 0.7.
- Can be installed while the ship is in operation.

Compact Selective Catalytic Reduction

The Selective Catalytic Reduction (SCR) process reduces NO_X emissions to harmless substances normally found in the air that we breathe.

SCR is currently the most efficient method of NO_X reduction. A reducing agent, such as an aqueous solution of urea, is injected into the exhaust gas at a temperature of 290-450 °C. The urea in the exhaust gas decays into ammonia, which is then put through a catalysing process that converts the NO_X into harmless nitrogen and water. The SCR method reduces NO_X emissions by 85-95%. Hence, it is easy to reach a NO_X level of 2 g/kWh or lower, which complies with the most stringent levels at sea.

SCR technology

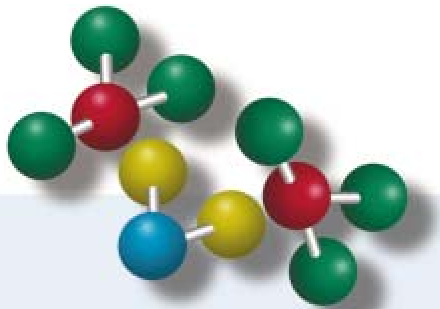
Compact SCR is a combined silencer and SCR unit – hardly any bigger than an ordinary silencer. A typical SCR plant consists of a reactor, which contains several catalyst layers, a dosing and storage system for the reagent, and a control system. The SCR reactor is a square steel container large enough to house the layers of catalytic elements.

The parameter for controlling the amount of urea injected is the engine load. To achieve more accurate control, the injection can be linked to feedback from a NO_X measuring device after the catalyst. The rate of NO_X reduction depends on the amount of urea injected, which can be expressed as the ratio of NH_3 to NO_X. The reduction rate can also be increased by increasing the catalyst volume.

If an exhaust gas boiler is specified, this should be installed after the SCR since the SCR requires a relatively high operating temperature.

The lifetime of the catalyst elements is typically 3-5 years for liquid fuels and slightly longer if the engine is operating on gas. The main running costs of the catalyst come from urea consumption and replacement of the catalyst layers. The urea consumption is about 15 g/kWh of 40 %-wt urea.

The size of the urea tank depends on the size of the engine, the load profile and how often the ship will be entering harbours where urea is available.



The chemistry of SCR

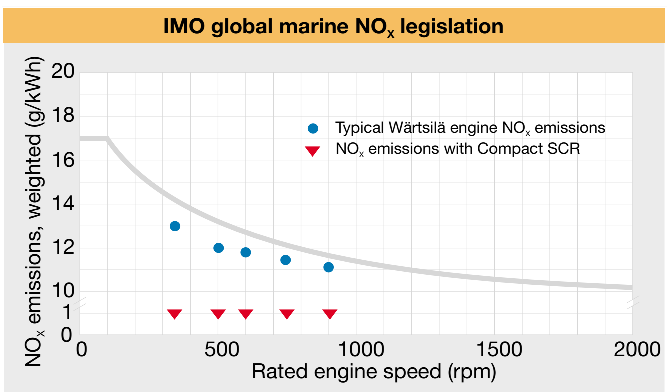
The reducing agent is urea (a 40 %-wt solution), which is a harmless substance used in the agricultural sector. The urea solution is injected into the exhaust gas directly after the turbocharger. Urea decays immediately to ammonium and carbon dioxide according to the following formula:

$(NH_2)_2CO + H_2O + \text{heat} \rightarrow 2\ NH_3 + CO_2$

The mixture is passed through the catalyst, where NO_X is converted to nitrogen and water:

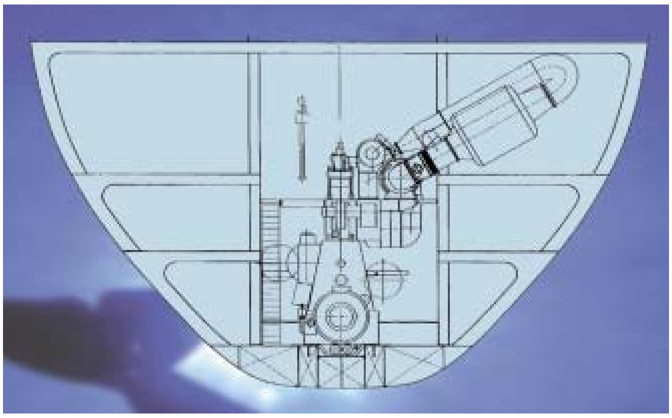
$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$



The standard Wärtsilä engines today fulfil IMO regulations.

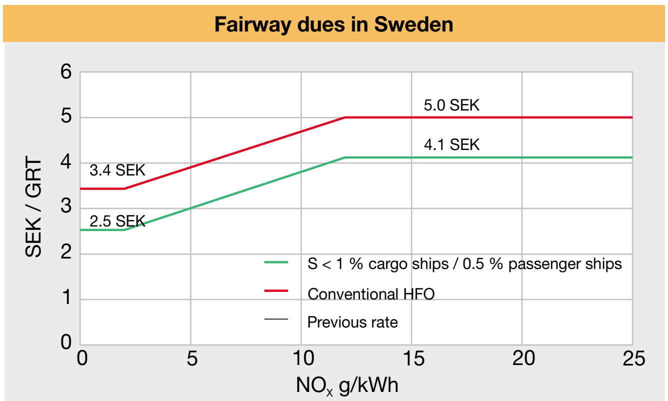
The Ro-Ro paper products carrier Spaarneborg and her two sisters are each powered by a Sulzer 7RTA52U main engine and two Wärtsilä 6L20 auxiliary engines. All engines are equipped with SCR systems to reduce NO_X emissions to the minimum.



Principal installation of a catalyst unit in a low-speed engine vessel. This is an ideal arrangement with respect to gas flow.
Other arrangements can be tailored to suit the ship design. The first ships to have Sulzer RTA engines with SCR units are three Ro-Ro vessels with seven RTA52U engines. These entered service in November 1999.

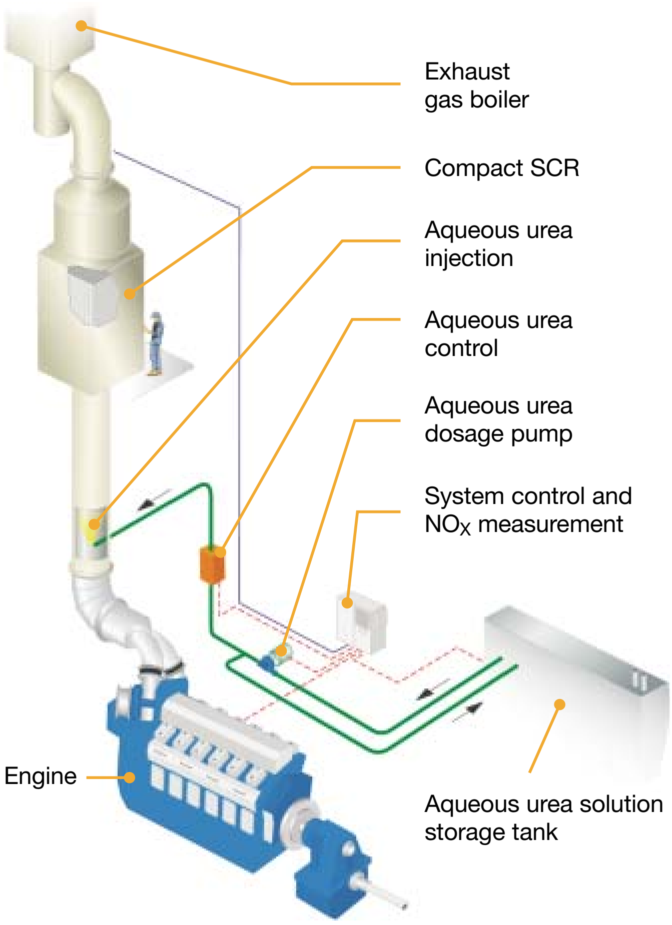
The Birka Princess, powered by four 12V32 main engines, two 6R32 and one 4R32 auxiliary engine, is equipped with Compact SCR units on all seven engines.

Tallink Victoria. Propulsion by four diesel engines totalling 26,240 kW. The catalytic reduction units installed for better control of exhaust emissions make the vessel most environmentally friendly.



Sweden has established its own system of differentiated fairway dues. This requires that vessels with higher NO_X emissions pay higher fees than environmentally-friendly ships of similar size.

Compact SCR technology is available for all engines in the Wärtsilä portfolio. Wärtsilä today has more than 190 SCR units for medium-speed marine engine and power plant installations either in operation or on order.



Compact SCR by Wärtsilä

- Combined silencer and SCR unit tailored for Wärtsilä engines
- Modular design enabling SCR retrofit
- Minimized size
- NO_X reduction 85-95 %
- Sound attenuation 25-35 dB(A)

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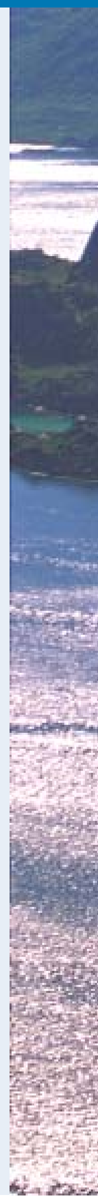

Wärtsilä is The Ship Power Supplier for builders, owners and operators of vessels and offshore installations. We are the only company with a global service network to take complete care of customers' ship machinery at every lifecycle stage.

Wärtsilä is a leading provider of power plants, operation and lifetime care services in decentralized power generation.

The Wärtsilä Group includes Imatra Steel, which specializes in special engineering steels.

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